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November 1, 1995

RJM

Mr. Jim Nelson
Intermountain Public Power District
850 West Brush Wellman Road
Delta, UT 84624-9546

RE: Flame Stabilizer Deformation

Dear Mr. Nelson:

We have completed our analysis of the flame stabilizer section that was sent to us.

The origin of the problem is high temperature deterioration via two separate paths as follows:

> **Path 1 Compressive Stress Buckling** - A temperature induced compressive stress on the trailing edge of the vanes causes the plastic buckling which is the wavy edge that is so obvious in the vane. This plastic buckling progressively grows due to a racheting mechanism as the swirlers heat up and cool down. I have included our internal memo on the stress analysis which provides a more detailed discussion of the buckling.
>
> Slotting the tip and root of the trailing edge of the blade ½ chord width as shown in my attached hand sketch corrects the buckling problem. This slot can be milled or cut into the swirlers which you now have in inventory.
>
> **Path 2 Surface Spauling** - The second path of deterioration is high temperature oxidation spauling of the 310 SS. Interestingly, we know that this type of phenomenon is greatly accelerated by high mechanical stresses. Therefore, the possibility exists that 310 SS may be adequate for service duty in your unit once the compressive buckling stresses are relieved by slotting the tip and roots of each vane.

The question now remains which material to use, 310 SS or HR160? Since a flame stabilizer made with HR160 vanes is twice the cost of a swirler made with 310 SS construction ($5400 vs. $2700), I recommend that the stress relieved swirler design be tested in 310 SS and HR160 materials to evaluation materials cost benefit relationship. If the 310 SS component in the stress relieved design is suitable for your service, IPP would be ahead of the game.

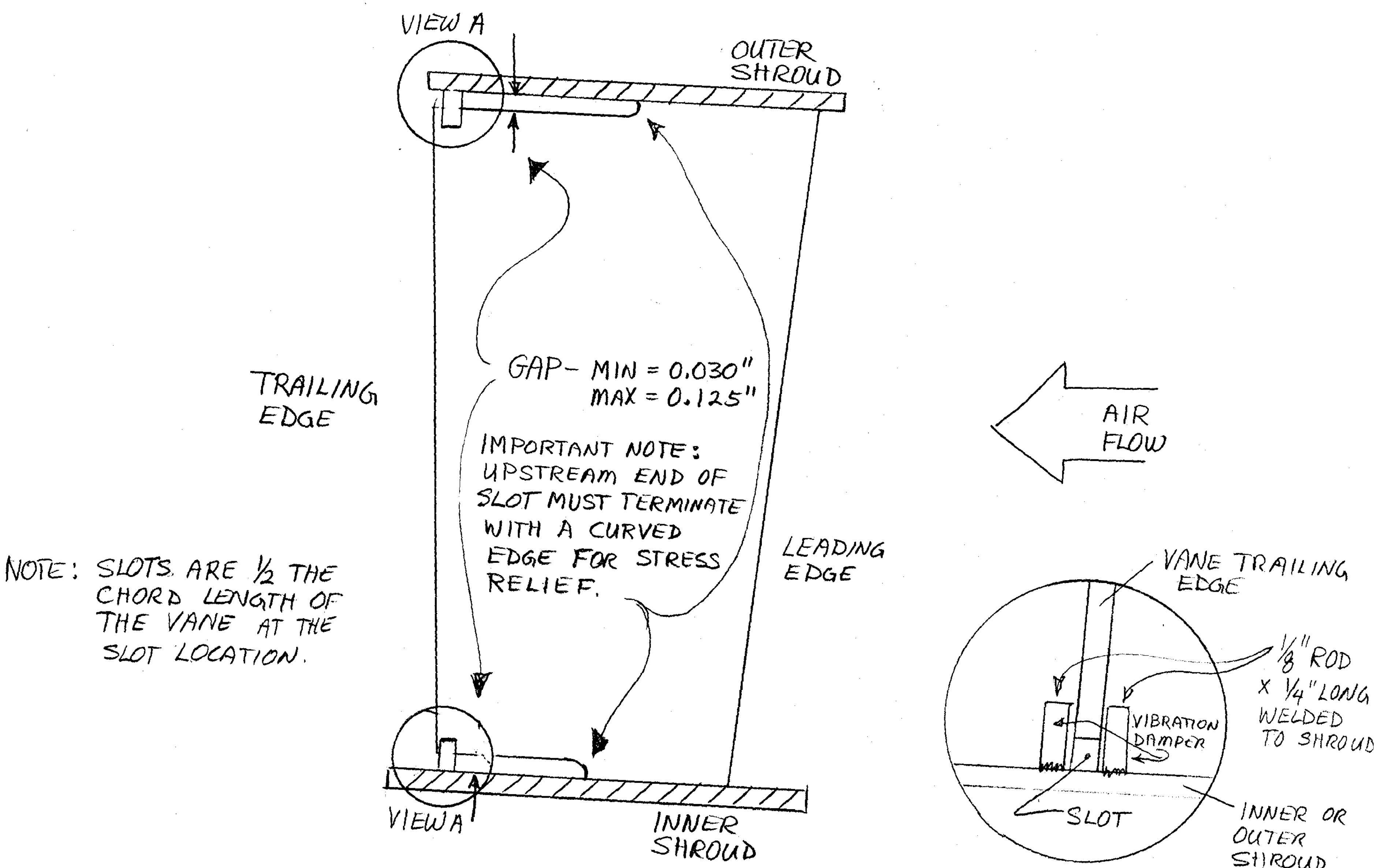
Another issue arises when we slot the trailing edge of the vane ½ chord length. The question is will the vane vibrate, and if so, will it produce a fatigue failure? Analysis indicates slotting the vane does result in a 100 hertz decrease in frequency in the lower frequency spectrum when compared to an unslotted vane arrangement. However, the question remains unanswered if there will be fatigue failure should this vane be excited by some furnace frequency which matches the frequency of the vane. Therefore, it is recommended that vibration dampeners be put on most of the new flame stabilizers as shown in the attached drawing. At least two (one of each material) should be constructed without the vibration dampeners for evaluation. Our best guess from the data is that we do not expect vibration fatigue problems to arise when vibration dampeners are not used. However, to err on the side of caution is prudent until testing proves vane dampeners are not necessary.

As you suggested, testing three clockwise swirlers of one material and three counter clockwise swirlers of the other material in the centerline burners would be an excellent way to test the price performance of these designs. You presently have more than three counter clockwise flame stabilizers which can be modified to the stress relief design. We can manufacture three clockwise swirlers with HR160 vanes in the stress relieved design for $16,200 FOB factory. Do you want us to proceed with this order?

Very truly yours,

Richard J. Monro
President

RJM/mer
Enclosure



VANE STRESS RELIEF GAPS
(DO FOR ALL VANES)

RJM 11/1/95

MEMORANDUM

TO: RICHARD MONRO

FROM: H.K.

SUBJECT: PLASTIC BUCKLING OF SWIRLER VANES

The trailing edges of the swirler vanes, P/N IPP-SWR-40-CW/CCW, showed them to be plastically buckled uniformly around the circumference, indicating that temperature induced compressive stresses on the trailing edges were caused by the restraint of the (colder) leading edges, rather than by the hoop restraint of the outer shroud.

Replacement of the 310 SS material with a higher yield strength material (HR160) was evaluated, along with design changes aimed at relieving the high compressive stresses in the trailing edge. The stress comparisons were made assuming a trailing edge temperature of 1350°F and a leading edge temperature of 950°F, giving a thermal straining gradient of 400°F.

The ultimate and yield strengths of HR160 are compared with 310 SS in Figure 1. In the temperature range of interest, the yield strength of HR160 is 40% higher than 310 SS. Figures 2 and 3 show that while the modulus of HR160 is approximately 12% higher than 310 SS, the coefficient of thermal expansion is approximately 12% lower, so that the thermal stress in the vanes should be essentially the same for either material. Resistance to buckling is dependent on the modulus only however, so it is increased approximately 12% using HR160.

For comparative purposes, the elastic stresses in the vane only were analyzed based on the flat-plate finite element model shown in Figure 4a. Boundary conditions along the hub and rim edges were specified to simulate the restraints of the inner and outer shrouds. The calculated temperature distribution based on leading and trailing edge temperature of 950°F and 1350°F is shown in Figure 4b.

As expected, the calculated stress patterns, shown in Figures 5a and 5b, are essentially the same for either material. These results also confirm that the trailing edge is being restrained from full thermal expansion by the leading edge, forcing the trailing edge into compression, the leading edge into tension. The stresses at the hub are generally higher than at the vane due to its smaller chord length. The high local stress concentrations seen in the corners will be relieved in practice by local plastic flow of the material which diffuses the load over the adjacent areas (not considered in this analysis).

The compressive stresses along the trailing edge are plotted in Figure 6 for comparison with the yield strengths of the two materials. It is seen that most of the trailing edge exceeds the yield strength of either material. It is expected therefore that for either material, the trailing edge would buckle plastically, relieving the compressive stress, and by so doing, would relieve some of the tensile stress in the leading edge. The leading edge tension stress pattern is plotted in Figure 7.

Here it is seen that most of the leading edge flows plastically for HR160, and all for 310 SS. In practice, this would in turn, relieve some of the compressive stress at the trailing edge.

Because of the stress relief provided by plastic flow, the actual stress values in the vanes would be somewhat less severe than calculated by these (elastic) analyses.

In an effort to relieve the high compressive stresses in the trailing edge before plastic buckling can occur, several design changes were evaluated. The first was to cut a slot along the hub, extending ½ chord length forward from the trailing edge. See Figure 8a. It is seen that this drastically reduces the stresses along the trailing edge, particularly near the hub.

The effect of cutting a ½ chord length slot along the rim boundary was also evaluated. See Figure 8b. This relieved the trailing edge stresses near the rim, but was only partially successful near the hub. The compressive stress pattern along the trailing edge for these two cases are plotted in Figure 9. It is seen that the hub slot reduced the trailing edge stresses everywhere below yield for either material. The corresponding tensile stress pattern on the leading edge, shown in Figure 10, becomes quite high near the hub, however, indicating that further stress relief may be desirable.

Accordingly, the effects of combining the slots at both hub and rim was also evaluated. Figures 11a and 11b show the stress relief obtained by two ¼ chord length slots and by two ½ chord length slots. The trailing edge compressive stresses are compared in Figure 12. The two ½ chord length slots were particularly effective, providing yield stress safety factors at the trailing edge of 1.5 for 310 SS, and 2.1 for HR160. The corresponding effect on the leading edge tensile stresses are shown in Figure 13. Here the two ½ chord slots bring the stresses down below yield over most of the span, but a small region near the hub still exceeds yield for either material. In practice, this would have to be accommodated by plastic flow of the material. In reality, the stress relief cuts in the shroud appear to satisfactorily relieve this region's yield stress.

The above analyses shows that ½ chord slots at both hub and rim will reduce the trailing edge stresses to below yield and so should effectively eliminate plastic buckling with either material. This modification will also reduce the leading edge stress to below yield over most of the span, again for either material. The margins of safety, however, are substantially higher for HR160 than for 310 SS, making it the preferred material based on thermal stress considerations.

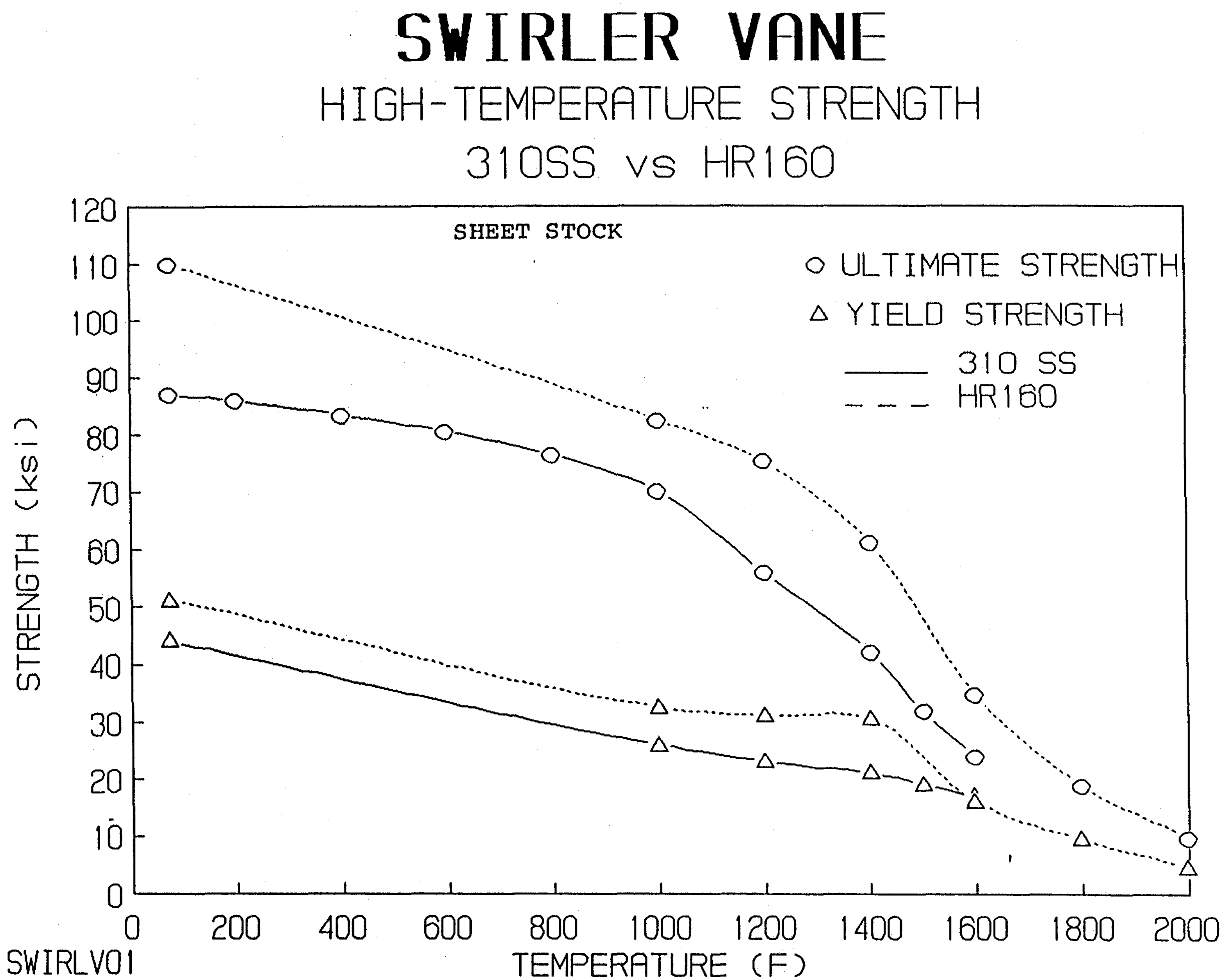


Figure 1 High Temperature Strength Comparison

IP7_003195

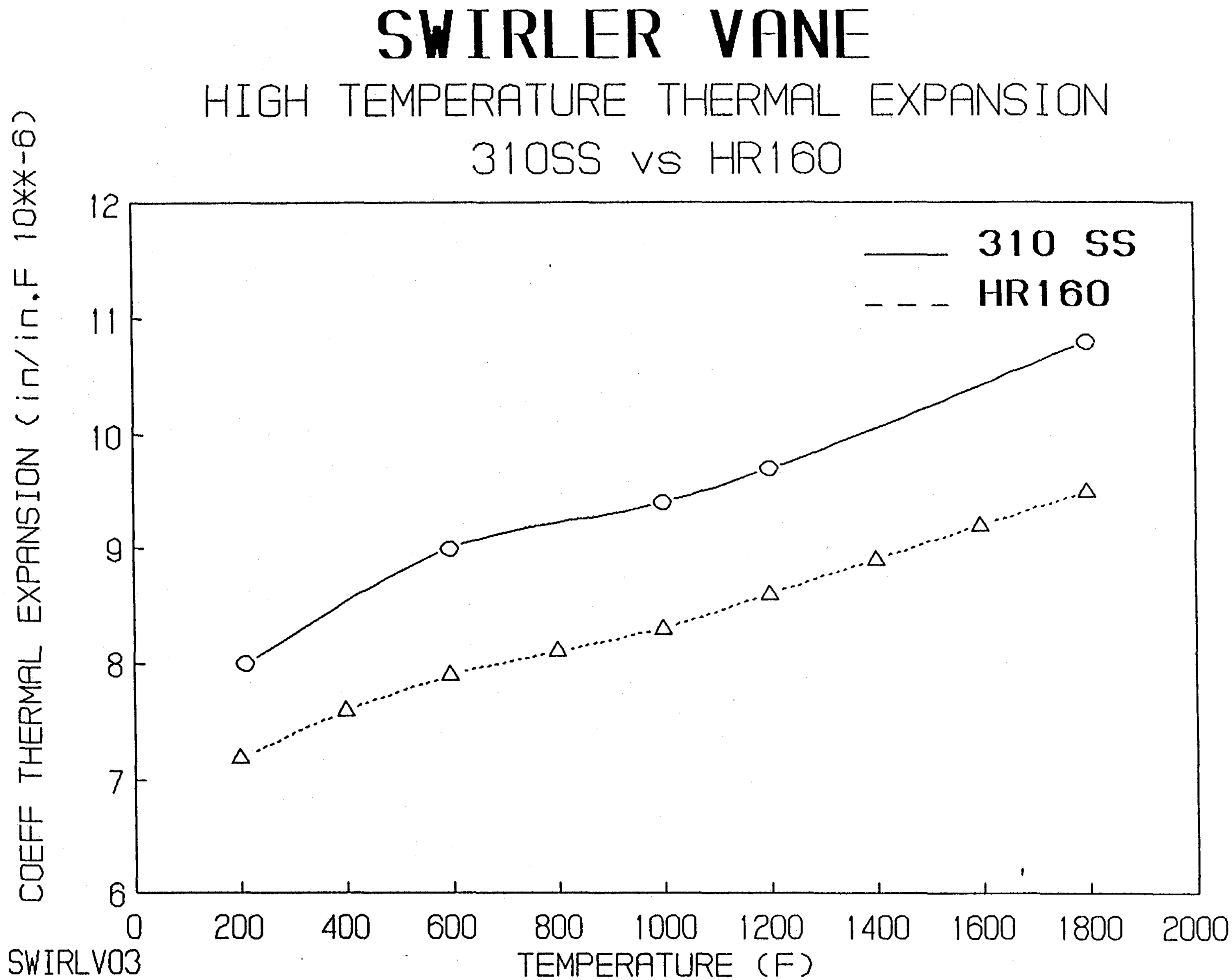


Figure 2 High Temperature Thermal Expansion Comparison

IP7_003196

11 x

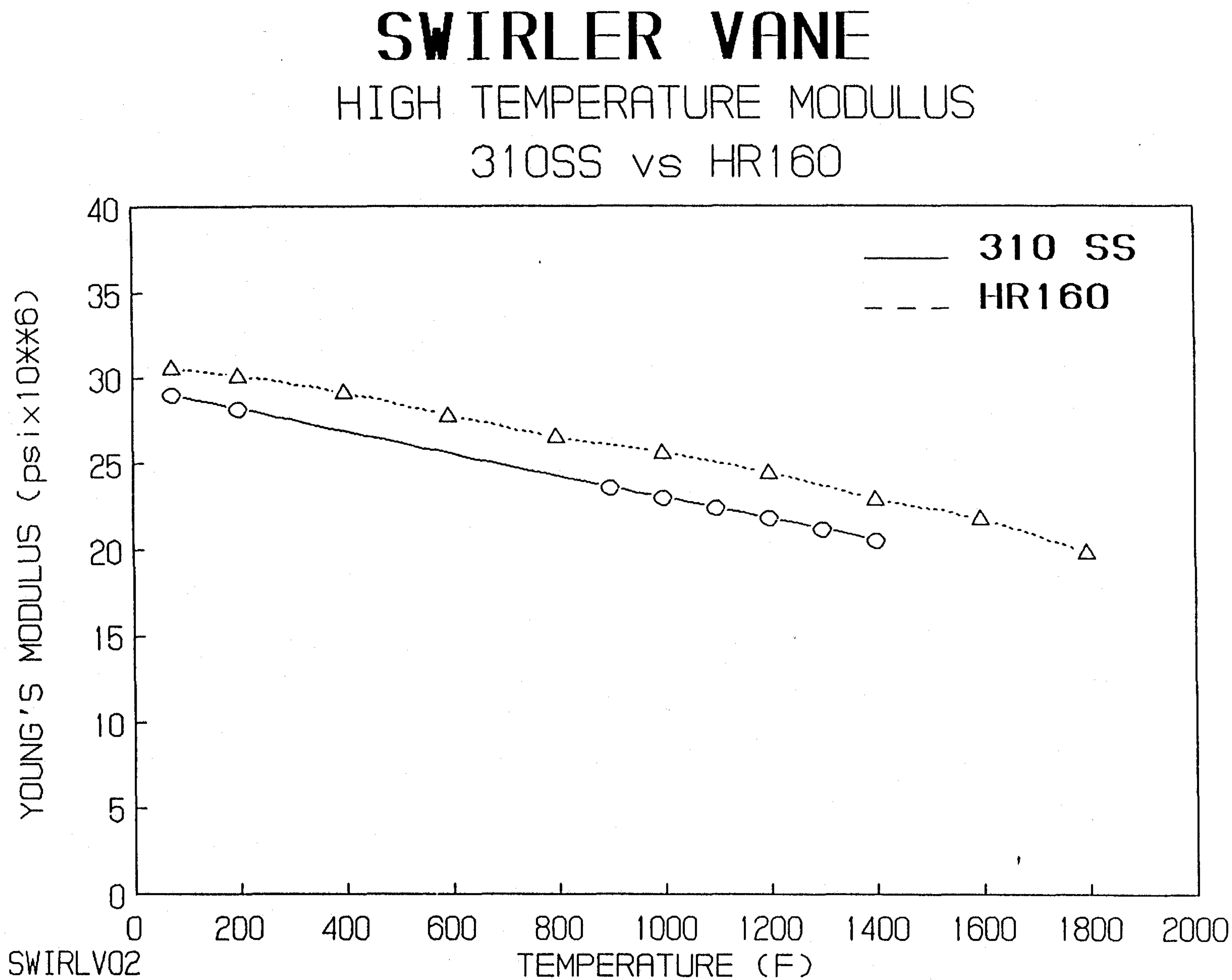


Figure 3 High Temperature Modulus Comparison

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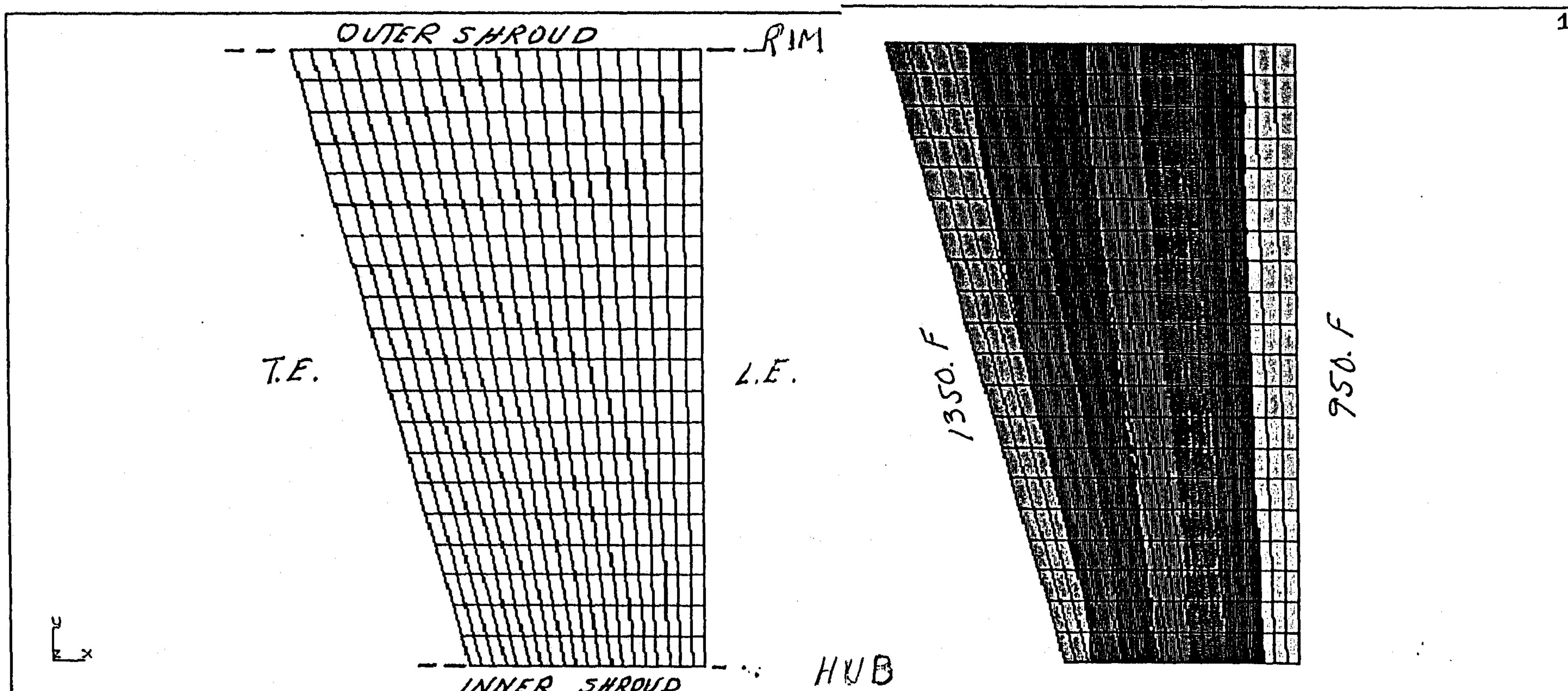

Figure 4 Finite Element Model and Temperature Distribution

IP7_003198

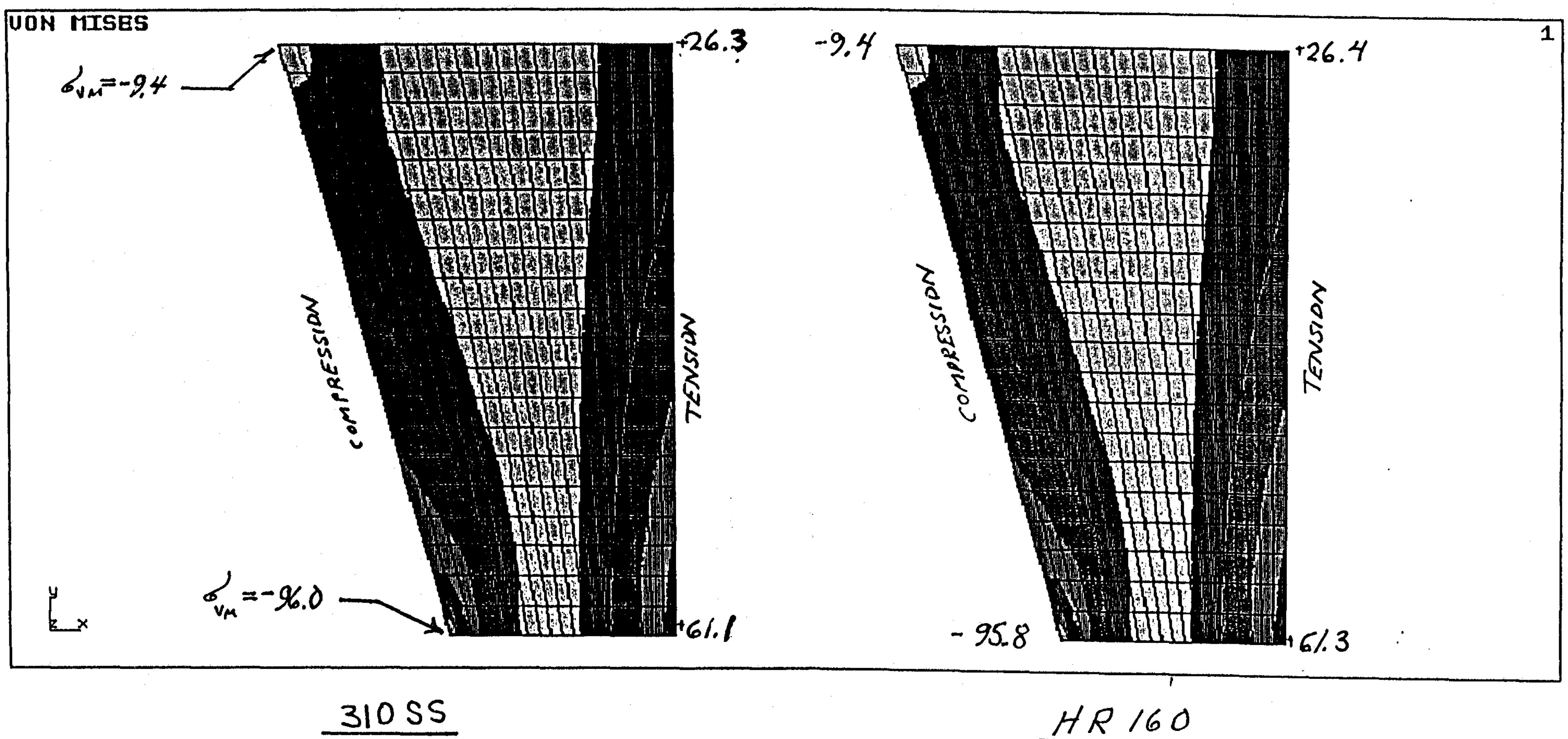

Figure 5 Stress Patterns Over Vane Surface

IP7_003199

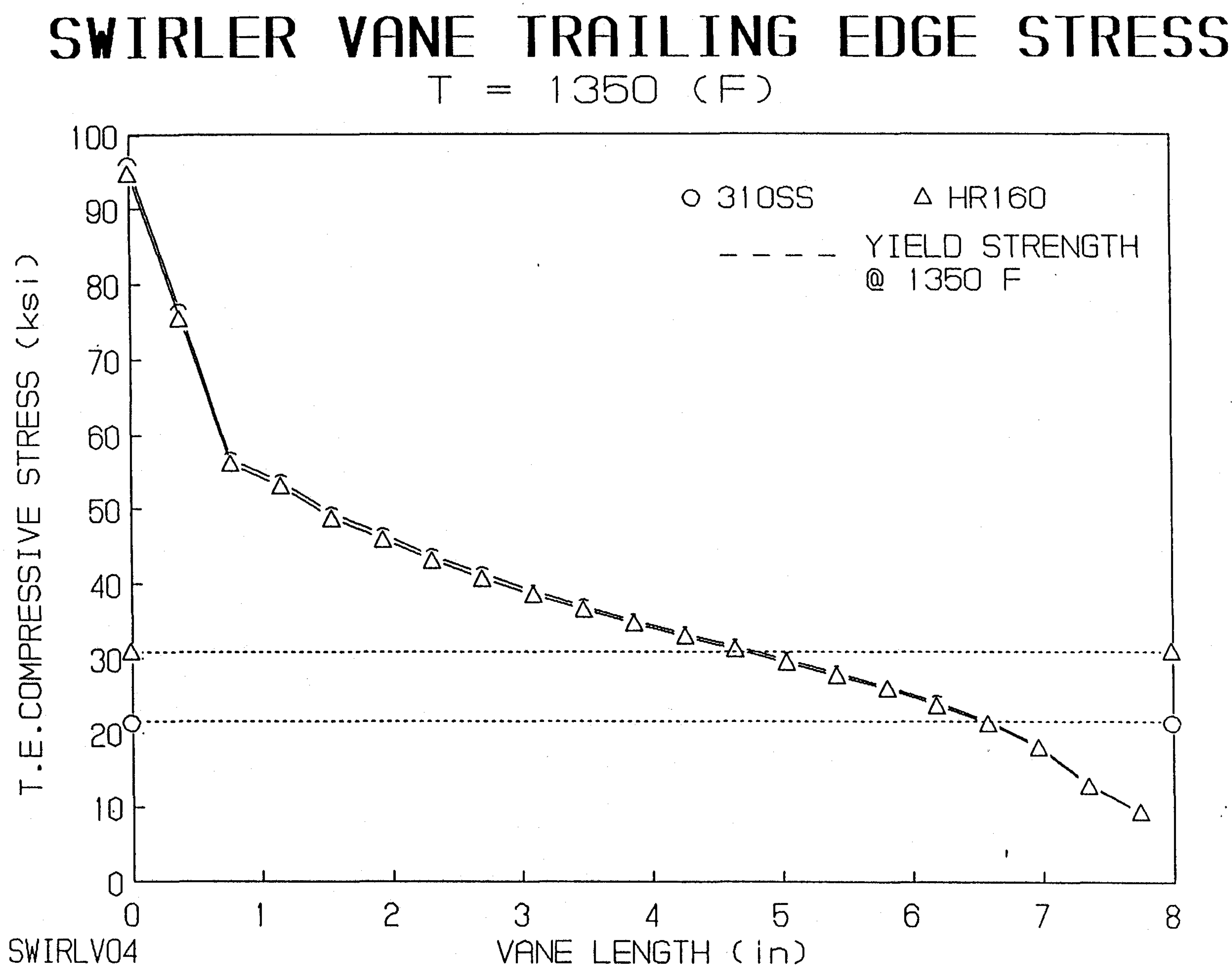

Figure 6 Compressive Stress Along Trailing Edge

IP7_003200

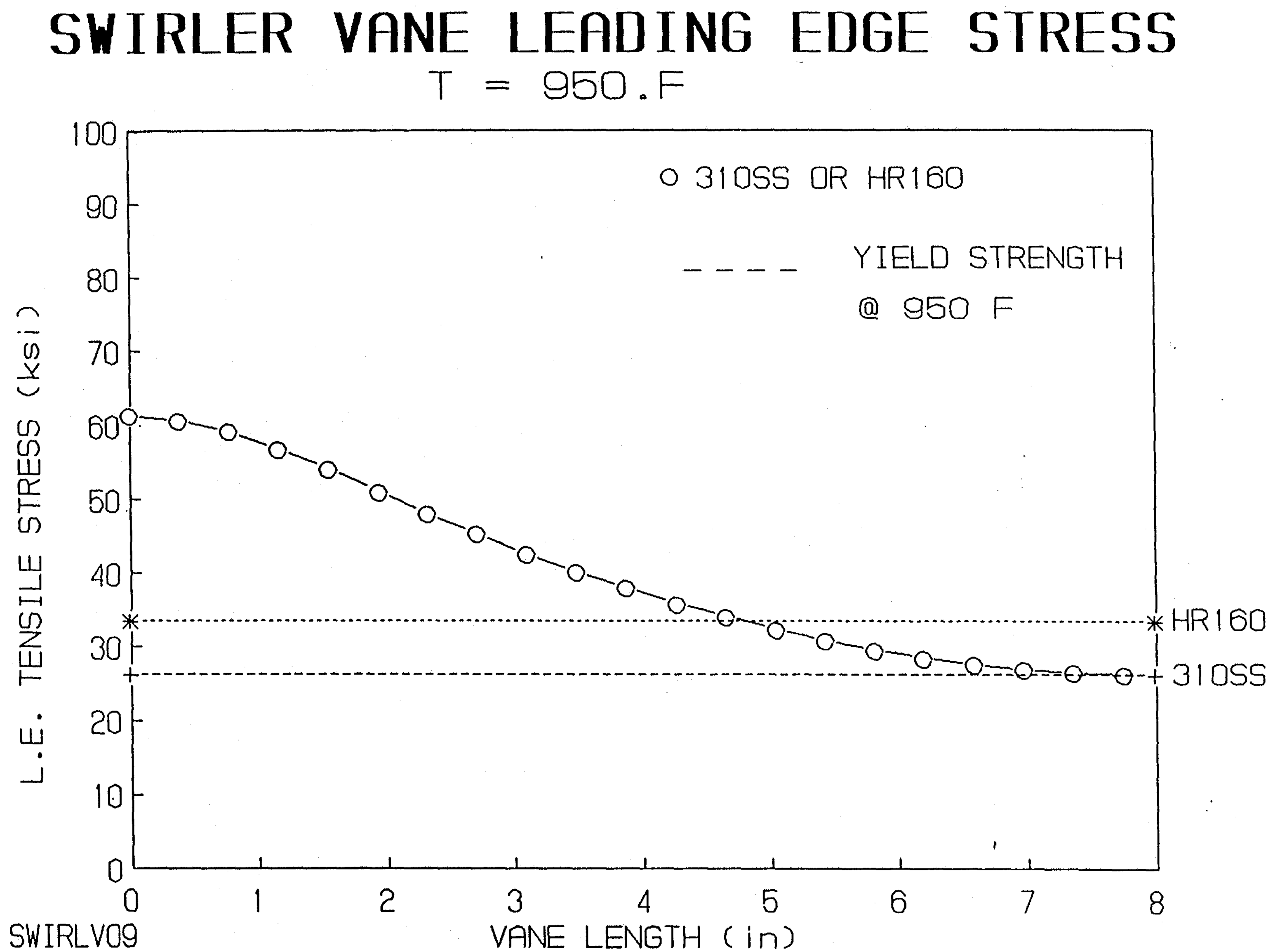

Figure 7 Tensile Stress Along Leading Edge

IP7_003201

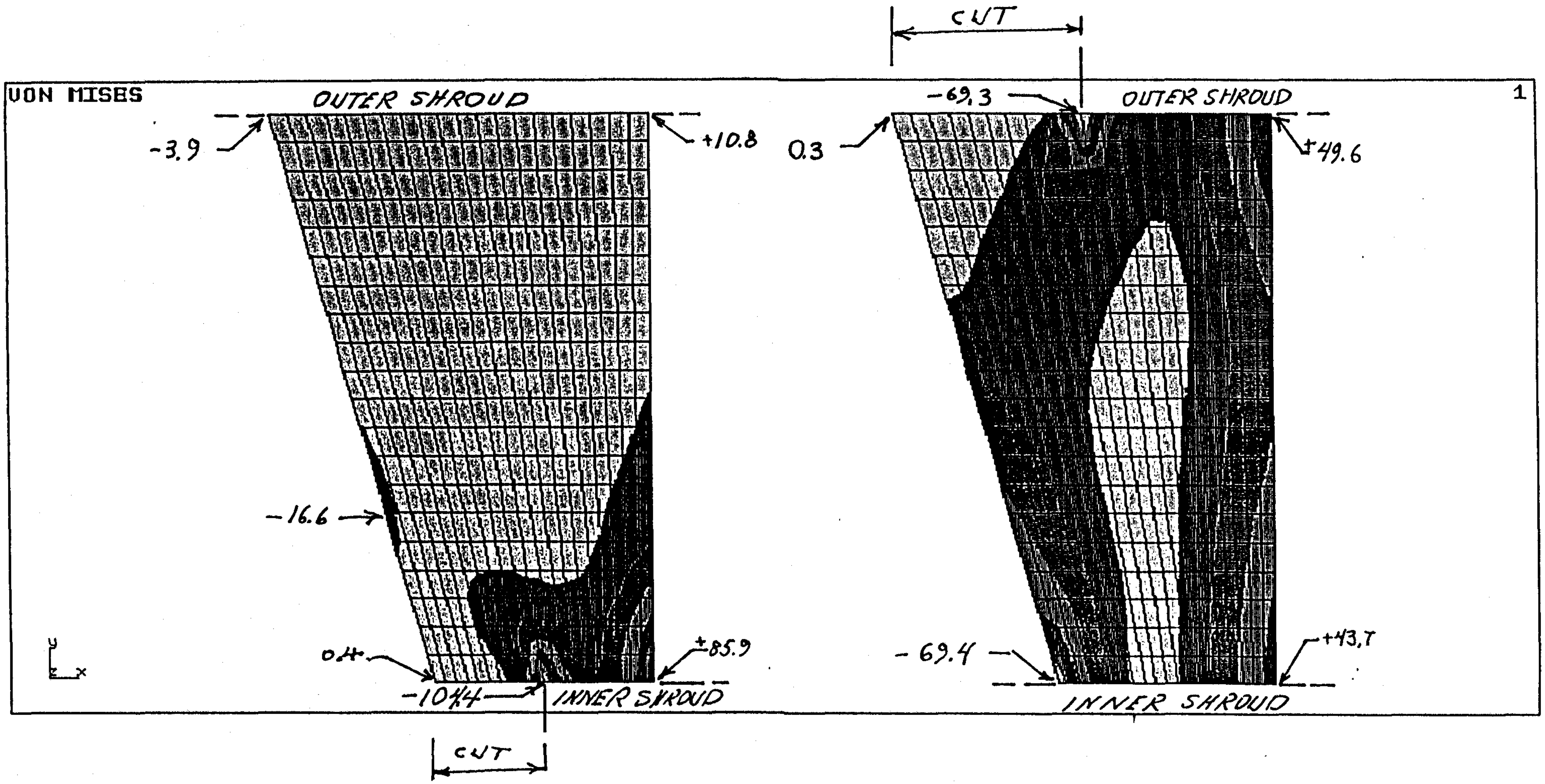

Figure 8 Stress Patterns Over Vane Surface

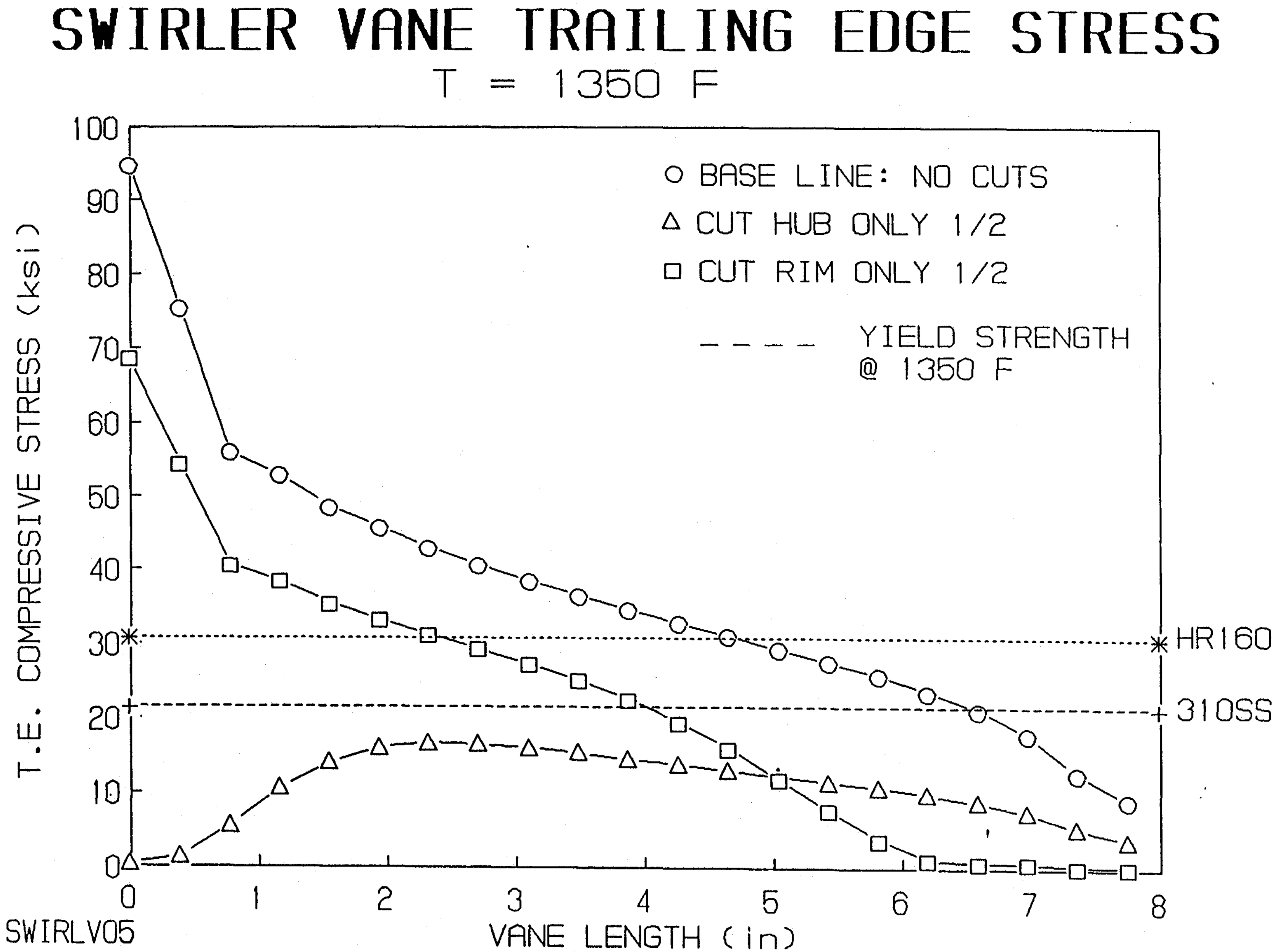

Figure 9 Compressive Stress Along Trailing Edge

IP7_003203

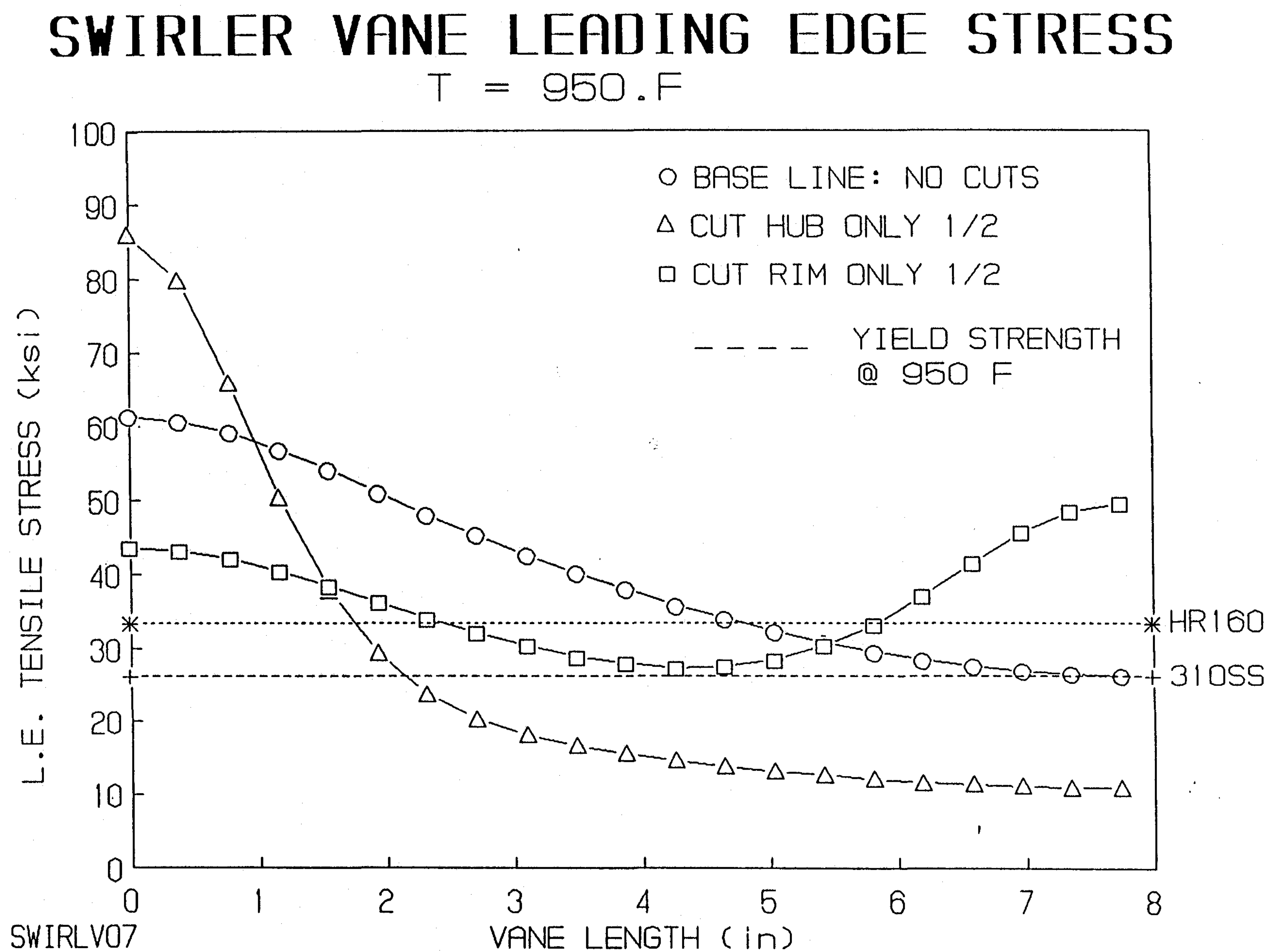

Figure 10 Tensile Stress Along Leading Edge

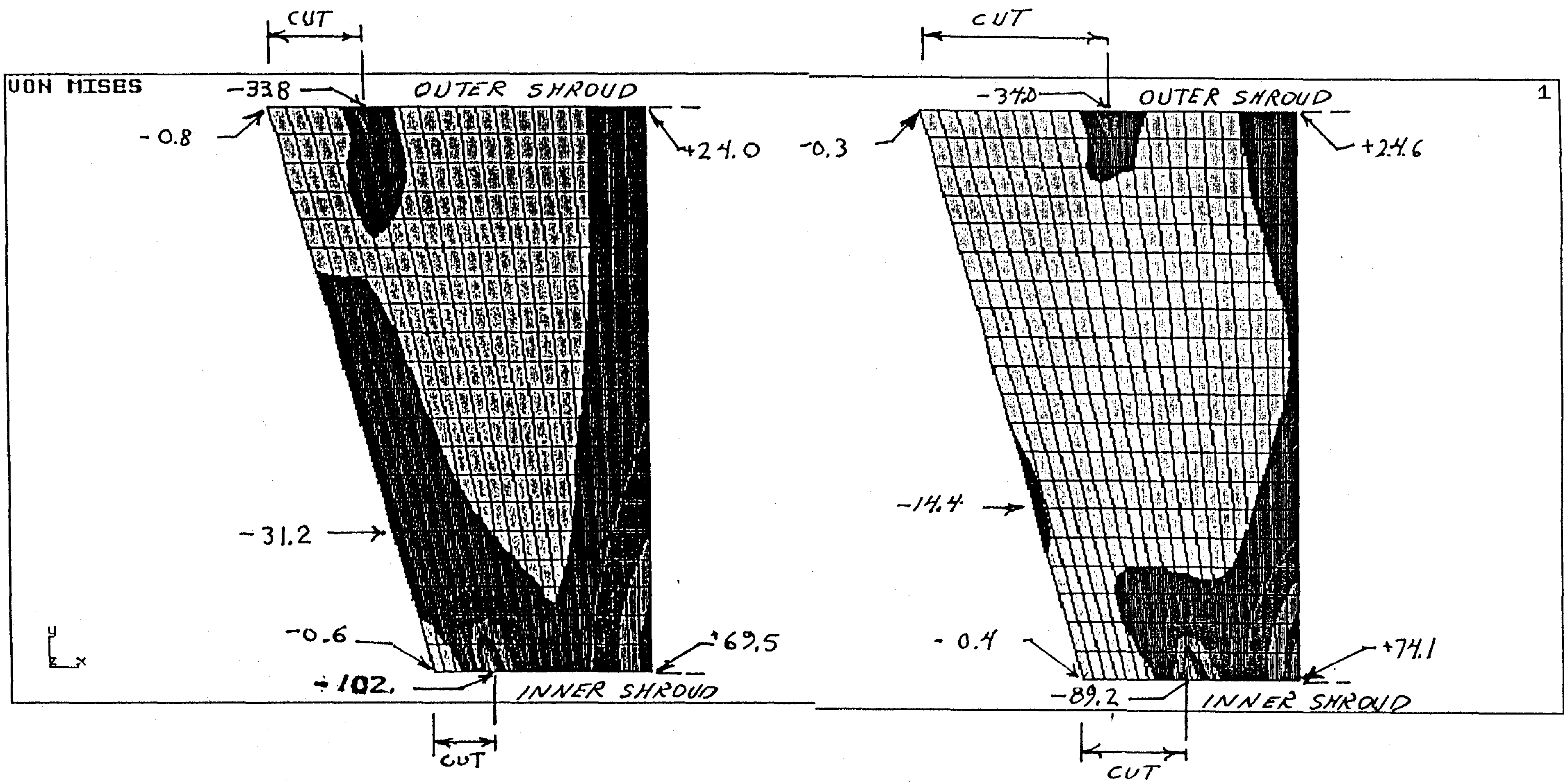

Figure 11 Stress Patterns Over Vane Surface

IP7_003205

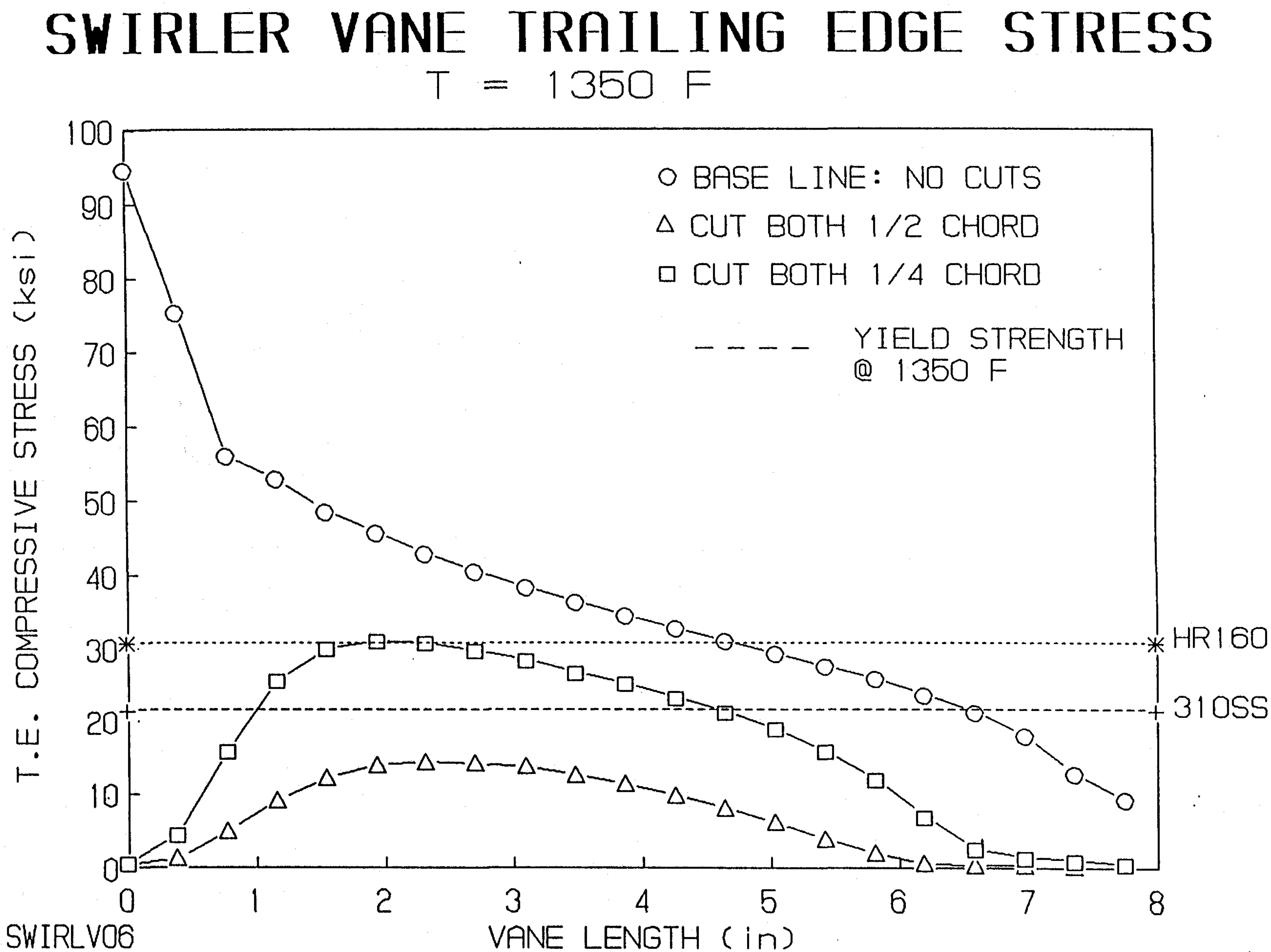

Figure 12 Compressive Stress Along Trailing Edge

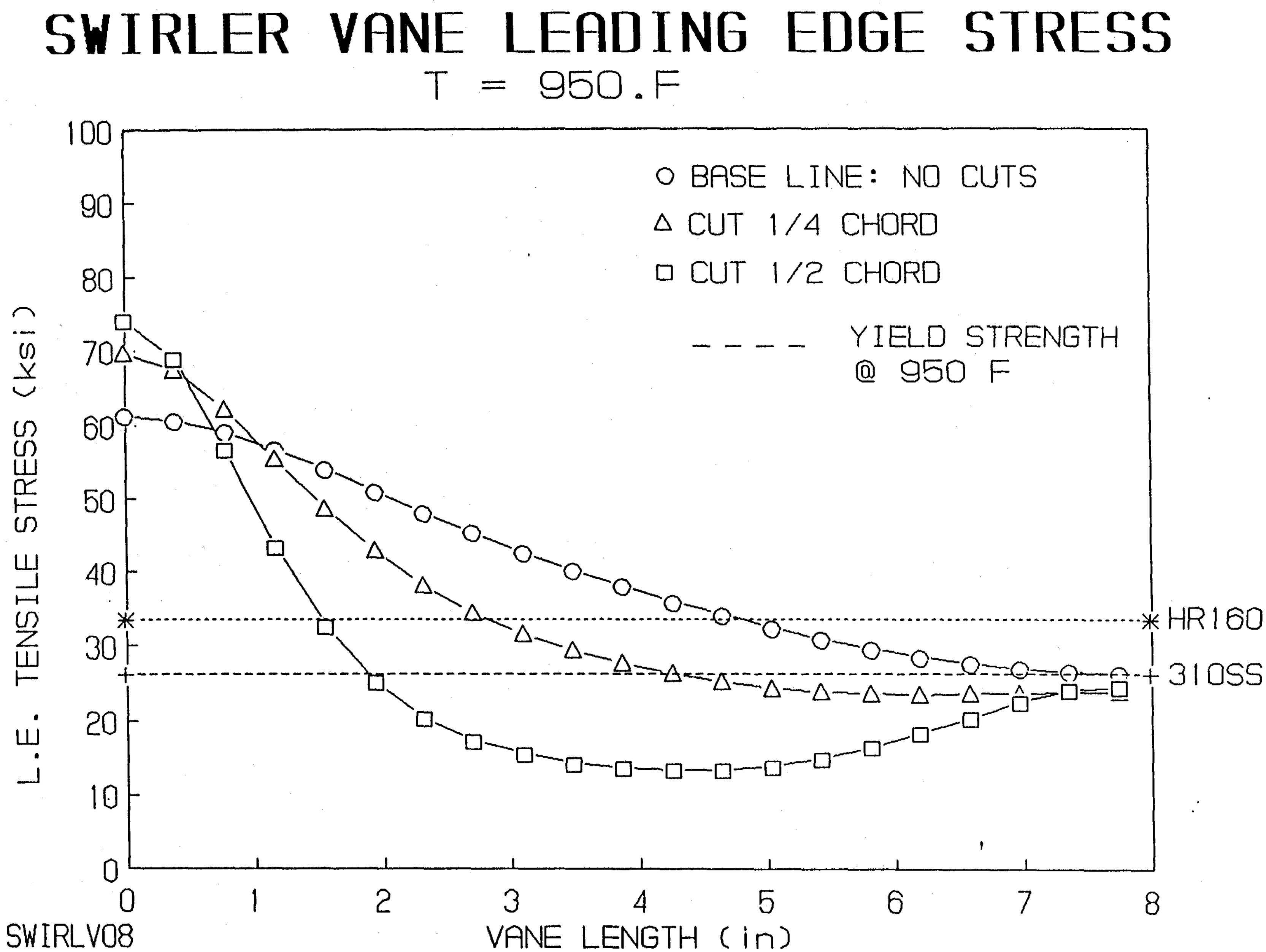

Figure 13 Tensile Stress Along Leading Edge

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